

National Aeronautics and
Space Administration



The Rover Flight Software of the VIPER Mission

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Outline

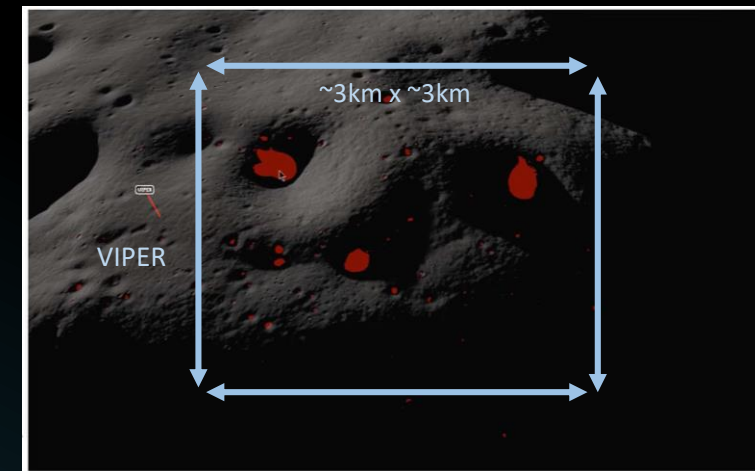
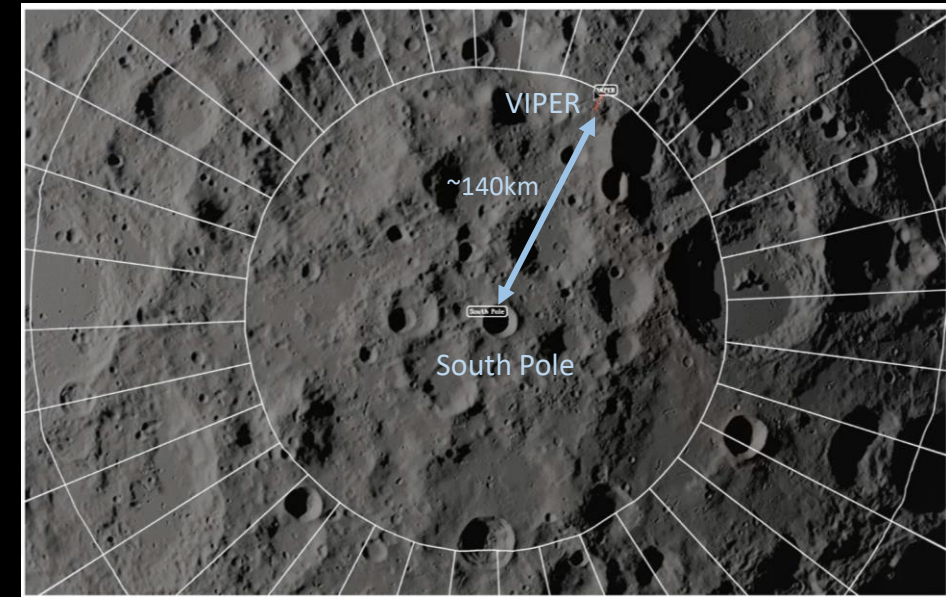
- VIPER Mission
- VIPER Rover Software
 - Rover Flight Software
 - Rover Ground Software
 - Rover Simulations
- Rover Software Development
- Status

The background of the slide is a high-contrast, black and white photograph of the lunar surface, showing numerous craters and craters. A solid blue horizontal band is positioned across the middle of the image, serving as a background for the title text.

VIPER Mission Overview


VIPER: Surface Mission at the Lunar South Pole

- NASA's VIPER Mission is sending a rover to the south pole of the moon (Nobile region)
- It's objective is to characterize the surface and subsurface water ice at the lunar south pole in and around permanently shadowed regions (PSR's)
- The rover is operated in continuous communication from earth
- Only survival functionality during out-of-comms configurations (earth below horizon etc.)
- As the rover is solar powered operations will be carefully aligned with the movement of the sun/shadows over the lunar pole
- The rover survives short polar summer nights and operations in PSR's on battery power



Screenshots
from the
VIPER
Traverse
Planning tool
/M. Shirley

VIPER Mission Parameters

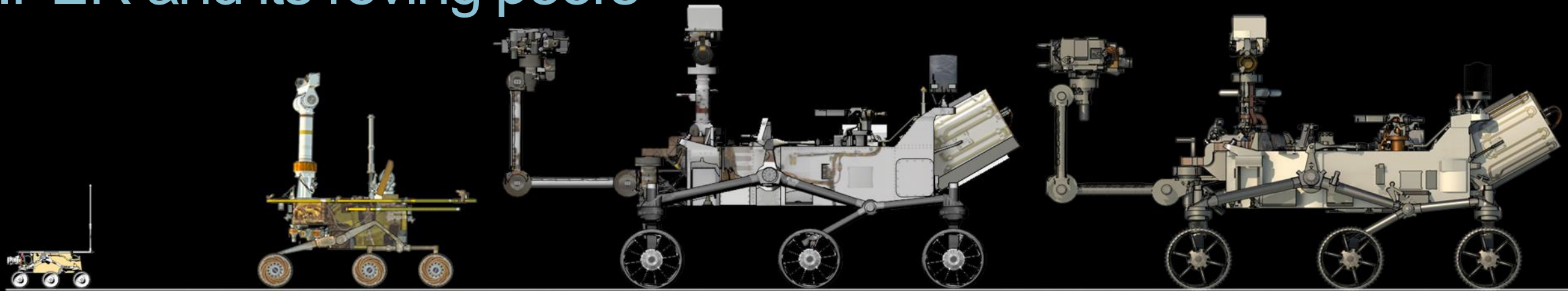
- 
- **Surface Duration:** ~100 earth days (4 lunar days)
 - **Instruments:** Neutron, Near-IR, and Mass Spectrometers; 1m Drill
 - **Drill Depth:** 1m (~3ft)
 - **# of Subsurface Assays (drill sites):** ~32
 - **Dark Survivability:** 50hrs
 - **PSR Working Duration (w/drill):** 10hrs
 - **Distance Travelled (goal):** ~27km (~17mi)

The VIPER Lunar Rover



aka VIPER Surface Segment

VIPER and its roving peers



Sojourner (1996)

0.6m x 0.5m x 0.3m

11kg

Top Speed: 0.5cm/s

Plutonium-238 RHUs

Mars Exploration Rover (2004)

1.6m x 2.3m x 1.5m

180kg

Top Speed: 5cm/s

Plutonium-238 RHUs

Mars Science Laboratory (2011)

3.0m x 2.8m x 2.1m

900kg

Top Speed: 4cm/s

Plutonium-238 MMRTG

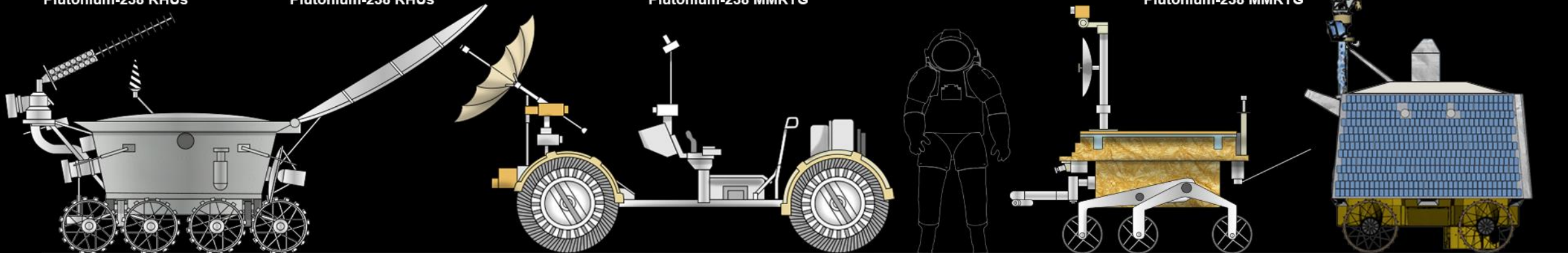
Mars 2020 Rover (2020)

3.0m x 2.7m x 2.2m

1025kg

Top Speed: 4.2cm/s

Plutonium-238 MMRTG



Lunokhod 1 & 2 (1970/1973)

2.3m x 1.6m x 1.5m

840kg

Top Speed: 55cm/s

Polonium-210 heat source

Lunar Roving Vehicle (1971/1972)

3.1m x 1.6m x 1.5m

210kg

Top Speed: 500cm/s

2 silver-zinc 36 volt batteries

Yutu (2013/2019)

1.5m x 1.1m x 1.1m

140kg

Top Speed: 5cm/s

Plutonium-238 RHUs

VIPER (2023)

1.5m x 1.5m x 2.0m

430kg

Top Speed: 20cm/s

Electric heaters only



VIPER Rover Parameters

- **Rolling Mass:** ~450kg (992lbs)
- **Communications:** X-band
 - 256kbps (DTE min.) / 2kbps (DFE min.) ¹
 - 6-15[s] round-trip latency / (24h x 14d x 3m)
 - Ground: DSN 34m dishes: Canberra, Goldstone, Madrid
- **Dimensions:** 1.7m x 1.7m x 2.5m (5ft x 5ft x 8ft)
- **Wheel Diameter:** 0.5[m] (20in)
- **Steering:** Explicit steer; adjustable suspension
- **Top Speed:** 20cm/s (0.5MPH)
- **Prospecting Speed:** 10cm/s (0.25MPH)
- **Waypoint Driving:** ~5m (16ft) command distance
- **Camera Look-ahead:** 8m (26ft)
- **Obstacles / Slopes:** 20cm (8in) / 15deg
- **Expected Cold Environment:** ~40K (-390degF)



¹ DTE = Direct-To-Earth / DFE = Direct-From-Earth

VIPER Instrument overview

Neutron Spectrometer System (NSS) NSS (NASA ARC, Lockheed Martin ATC)

PI: Rick Elphic (NASA ARC)

Prospects for hydrogen-rich materials while roving, mapping the distributions



Instrument Type: Two channel neutron spec

Key Measurements: NSS assesses hydrogen and bulk composition in the top meter of regolith, measuring WEH while roving

Operation: On continuously while roving

Specs: 1.9kg, 1.6W, 21x32x7cm (sensor) / 14x18x3cm (Data proc. module)

Near InfraRed Volatiles Spec. System (NIRVSS)

NIRVSS (ARC, Brimrose Corporation)

PI: Anthony Colaprete (NASA ARC)

Prospects for surface water “frosts” and evaluates excavated materials



Instrument Type: NIR Point Spectrometer, 4Mpxl Panchromatic Imager w/7 LEDs, 4-ch thermal radiometer

Key Measurements: Volatiles including H₂O, OH, and CO₂ & mineralogy, surface morphology/temps

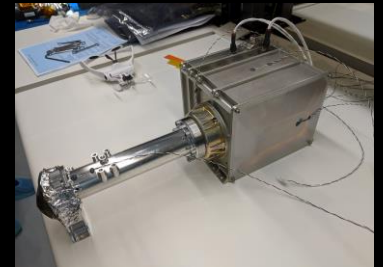
Operation: On continuously while roving and during drill operations

Specs: 3.6kg, 29.5W, 18x18x9cm (spec) / 20x13x15cm (Obs bracket)

Mass Spec. Observing Lunar Operations (MSolo) MSolo (KSC, INFICON)

PI: Janine Captain (NASA KSC)

Prospects for surface volatiles while traversing and during drilling



Instrument Type: Quadrupole mass spectrometer

Key Measurements: Identify low-molecular weight volatiles between 1-100 amu, unit mass resolution to measure isotopes including D/H and O¹⁸/O¹⁶

Operation: Views drill cuttings, volatile analysis while roving and during drill activities

Specs: 6.0kg, 35W, 16x20x46cm

The Regolith and Ice Drill for Exploring New Terrains (TRIDENT) Drill

TRIDENT (Honeybee Robotics)

PI: Kris Zacny (Honeybee)

Excavates lunar regolith to 1-meter and measures forces, displacements and temperatures for regolith bulk properties

Instrument Type: 1-meter hammer drill

Key Measurements: Excavation of subsurface material to 100 cm; Subsurface temperature vs depth; Strength of regolith vs depth

Operation: Subsurface assays to 100 cm in <1 hr, depositing cuttings at surface

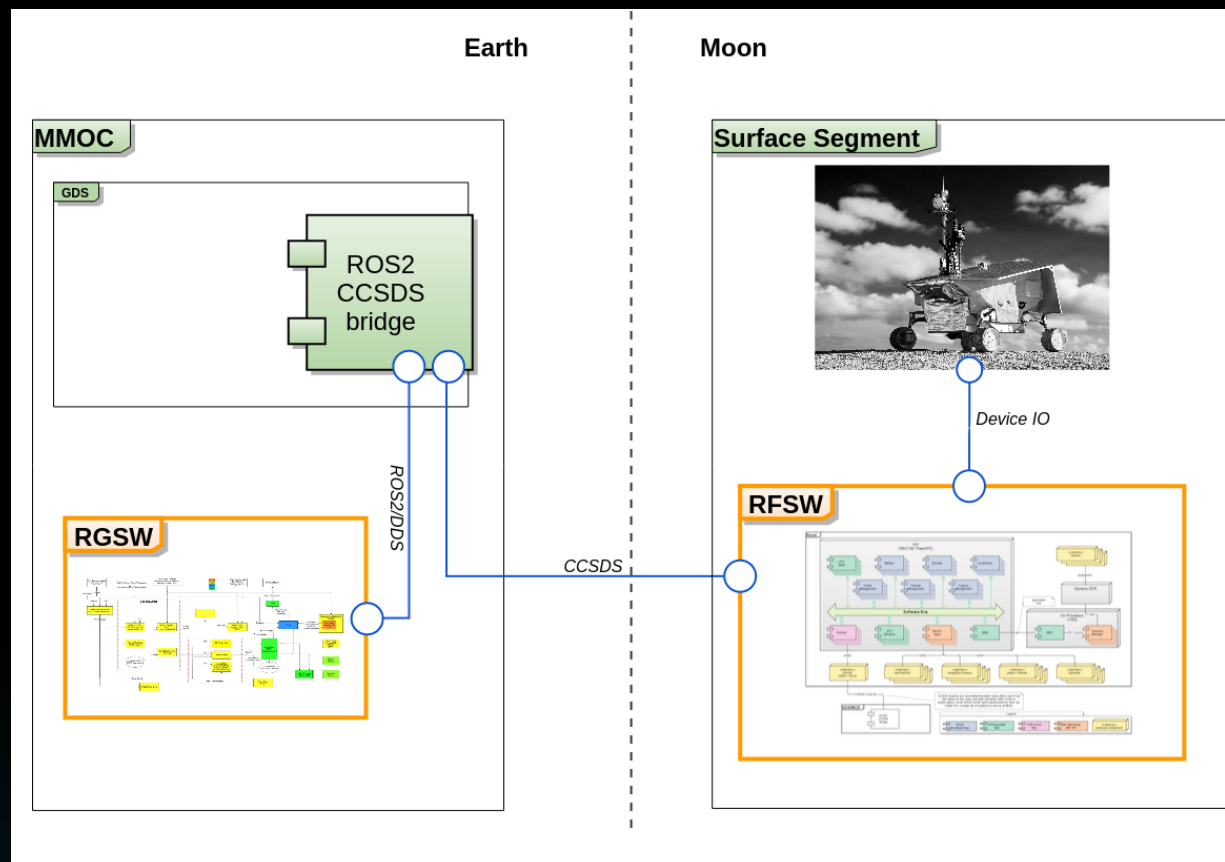
Specs: 18kg, 20W/175W (nom/max), 27x22x177cm



Software Architecture

Rover Software split architecture

- On-board - Rover Flight Software (RFSW)
 - Flight HW management
 - Operational safety
 - Basic rover surface mobility
- Off-board - Rover Ground Software (RGSW)
 - Deployed on the ground
 - Mobile robotics functions

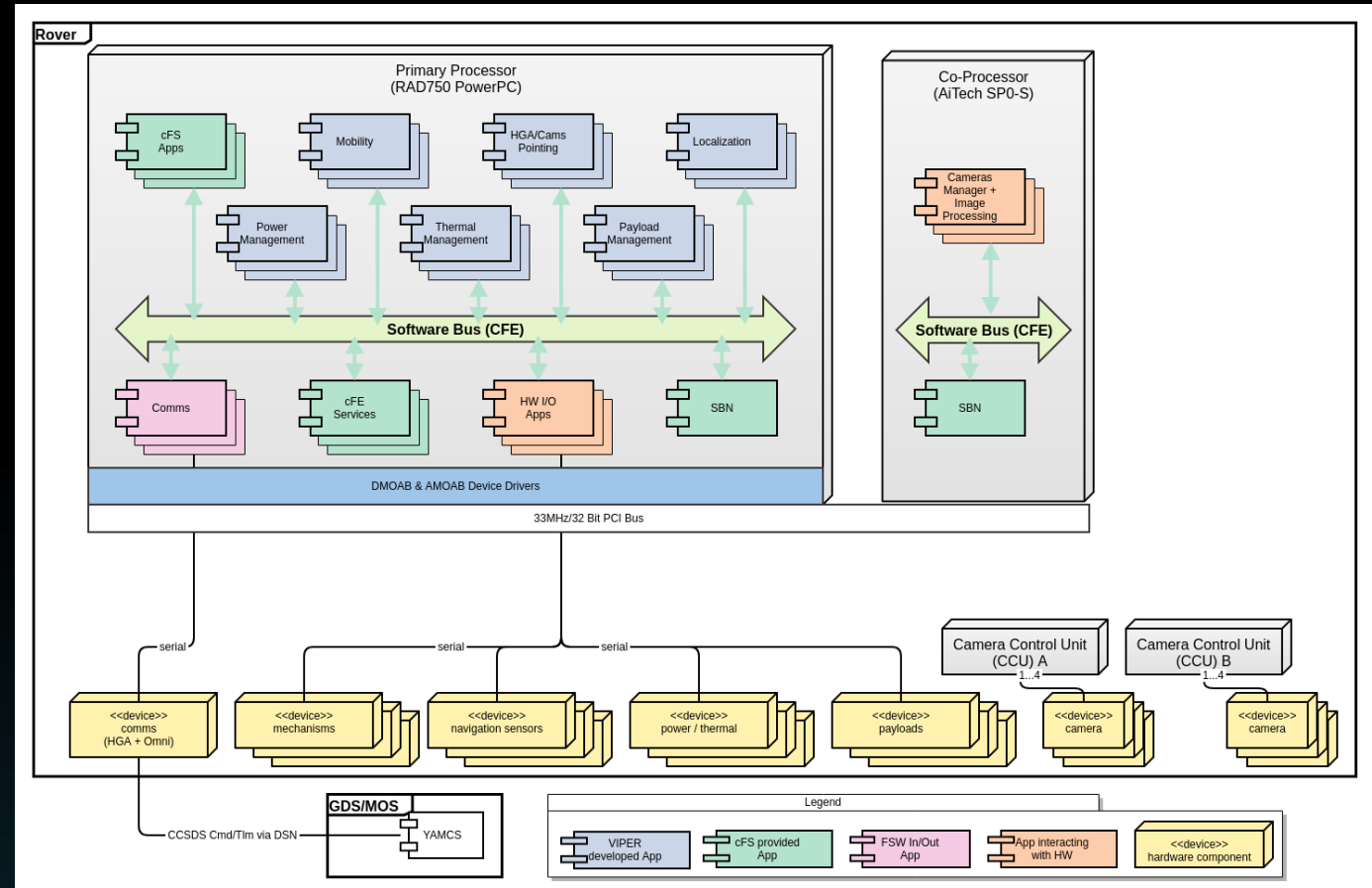




Rover Flight Software (RFSW)

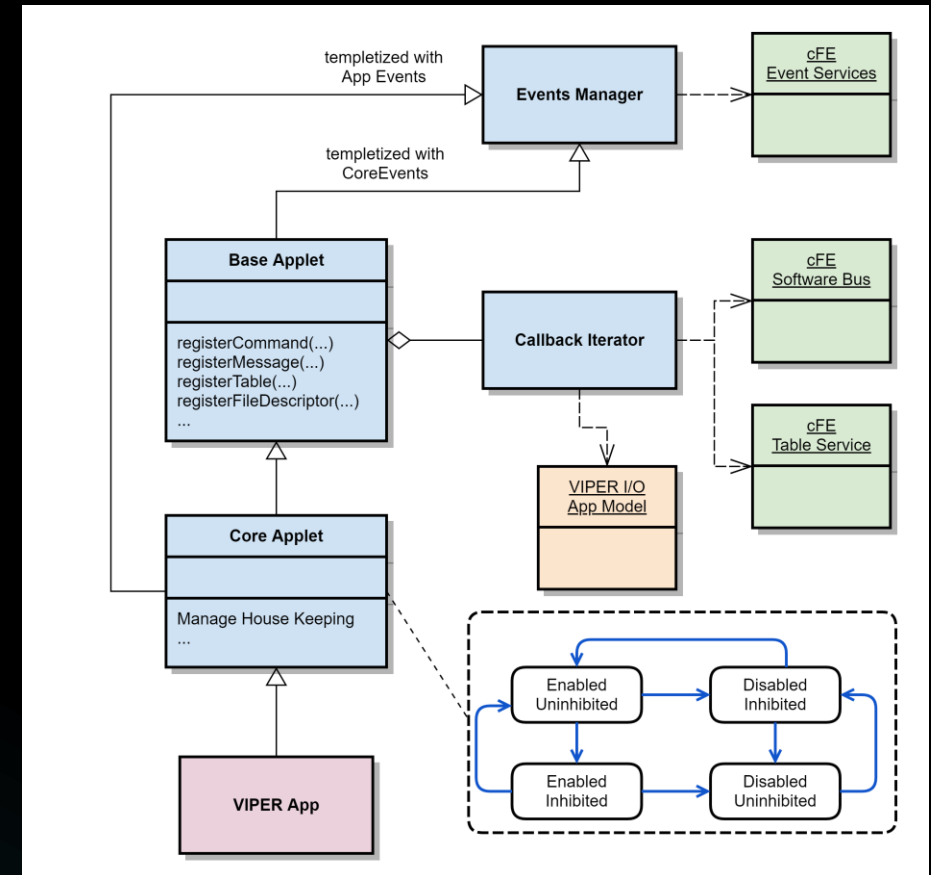
Rover Flight Software

- Based on the NASA cFE/cFS middleware
- Implemented in C++
- Target platform is 2 PPC computers running VxWorks
 - Radiation hard main processor (RAD750, 200MHz, 1GB RAM)
 - Radiation hard co-processor (SP0-S, 1GHz, 1GB RAM)



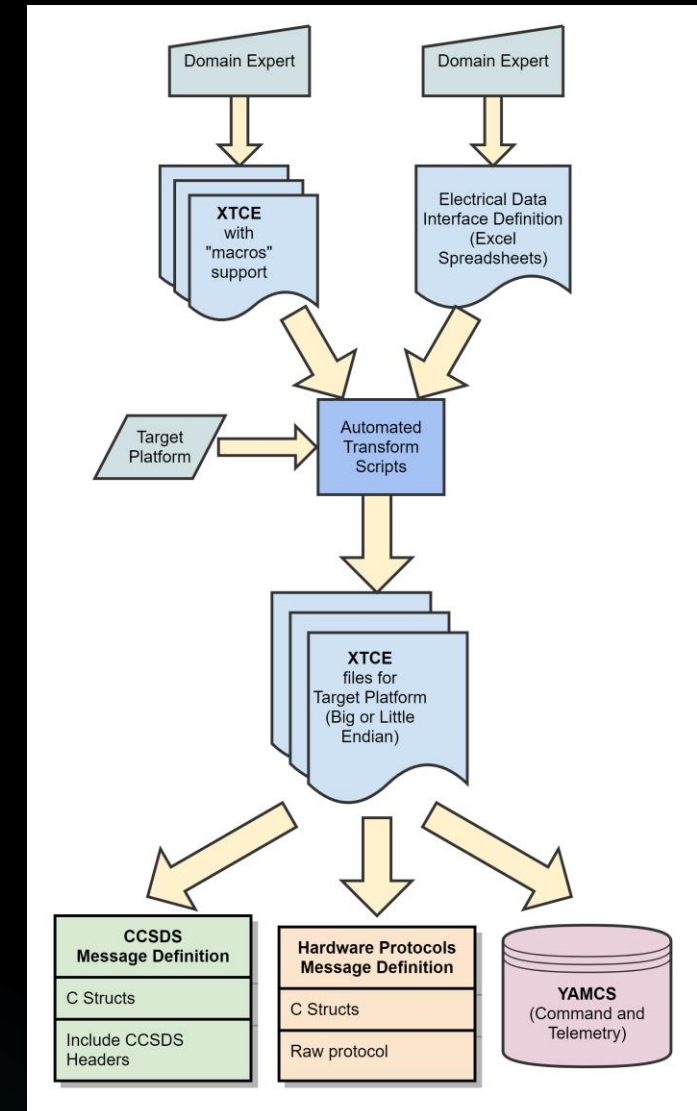
CoreApplet – cFE/cFS C++ Wrapper

- RFSW is based on NASA's cFE/cFS framework
 - Set of middleware services (cFE services)
 - Set of general purpose applications (cFS apps)
- CoreApplet
 - Small C++ framework (8 classes)
 - Wrapper of cFE services (ES, SB, TBL, EVS)
 - Event-based programming model
 - Function pointer callbacks
 - Strongly typed via C++ templates
 - Multiplexing multiple even sources
 - Software bus messages
 - Table updates
 - Device reads
 - Hooks for common cFS functions
 - Housekeeping telemetry requests
 - cFS app state model: enable/disable
 - IO abstraction for device communication
 - Multiplexing via select()
Adapted cFE to make SB message queues selectable, too
 - Half sync half async pattern



Interface Definitions (XTCE)

- XTCE
 - Interface definition language (IDL) for the YAMCS ground system
 - XML dialect describing types, data structures in complex detail
 - cFE/cFS does not provide it's own IDL
- Used for all interface definitions
 - Ground to RFSW
 - RFSW to hardware devices
 - RSIM using device XTCE for implementing device interfaces
- Single source of interface definition for different services and targets
 - Big endian and little endian targets (PPC & x86 Linux)
 - Filter tables for TelemetryOut (TO) and DataStore (DS) apps
 - Telemetry limit checker (LC) definitions for fault management
 - Binary on-board command sequences (RTS & ATS)

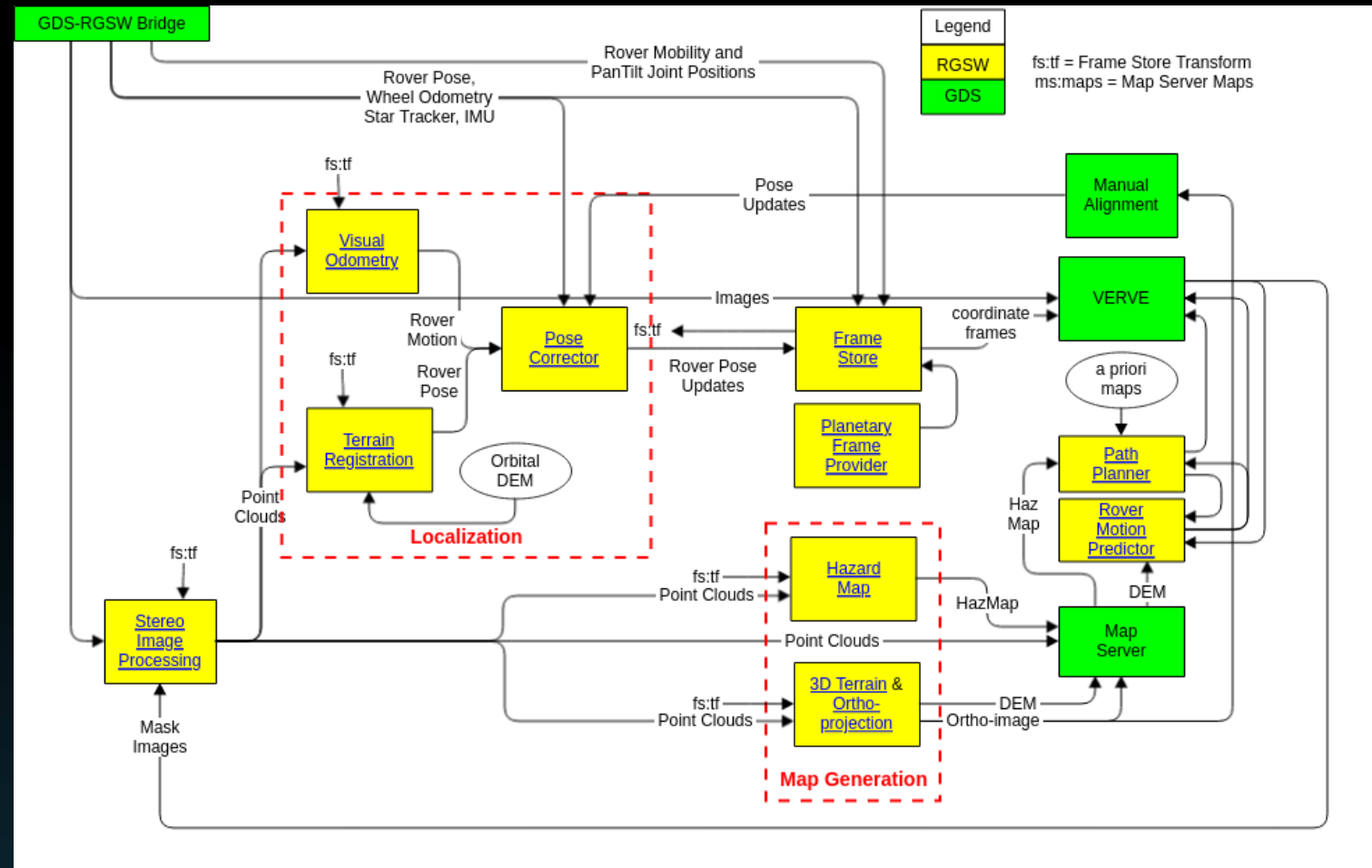


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VIPER Rover Ground Software (RGSW)

Rover Ground Software Architecture

- Based on ROS2
- Deployed on the ground
- Linux workstations
- Large eco-system of Open Source robotics software
- Extended with mission specific functions and algorithms

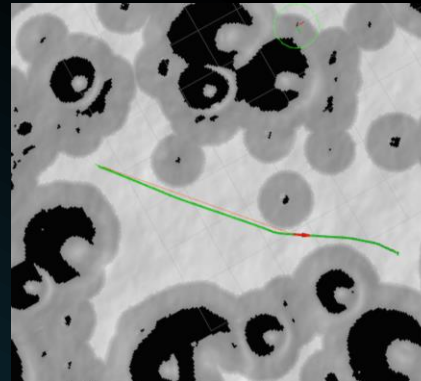
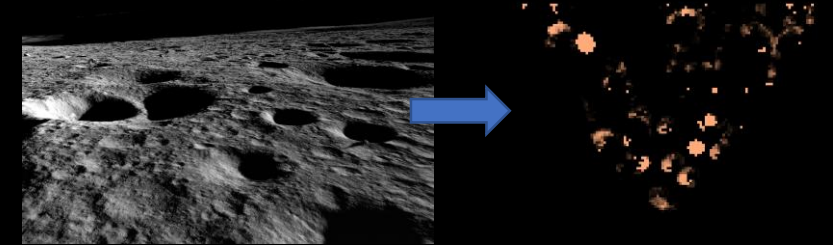
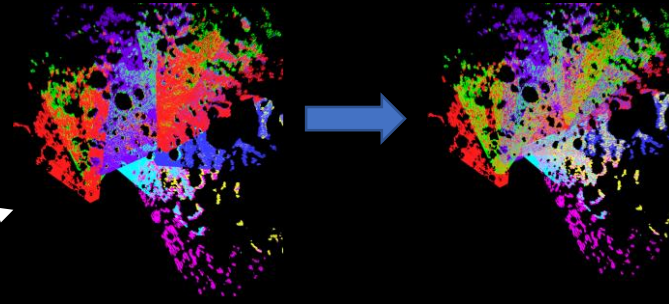


Rover Ground Software Scope

Robotic functionality that would typically reside on-board a rover

- Visual odometry for relative pose estimation
- Mapping and terrain analysis
- Path planning for human operator support
- ...

Designed as an “advanced driver assist system” (ADAS)

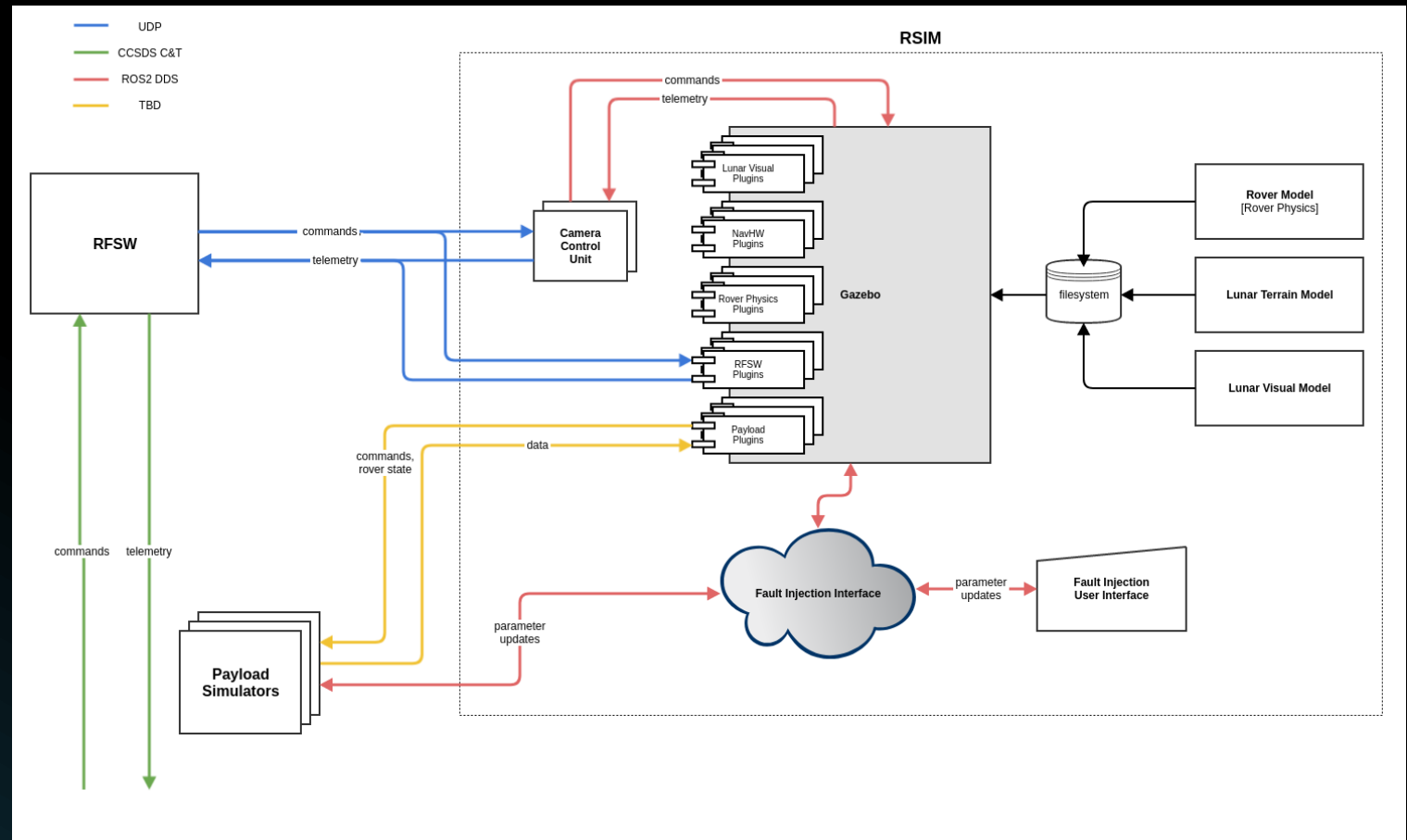


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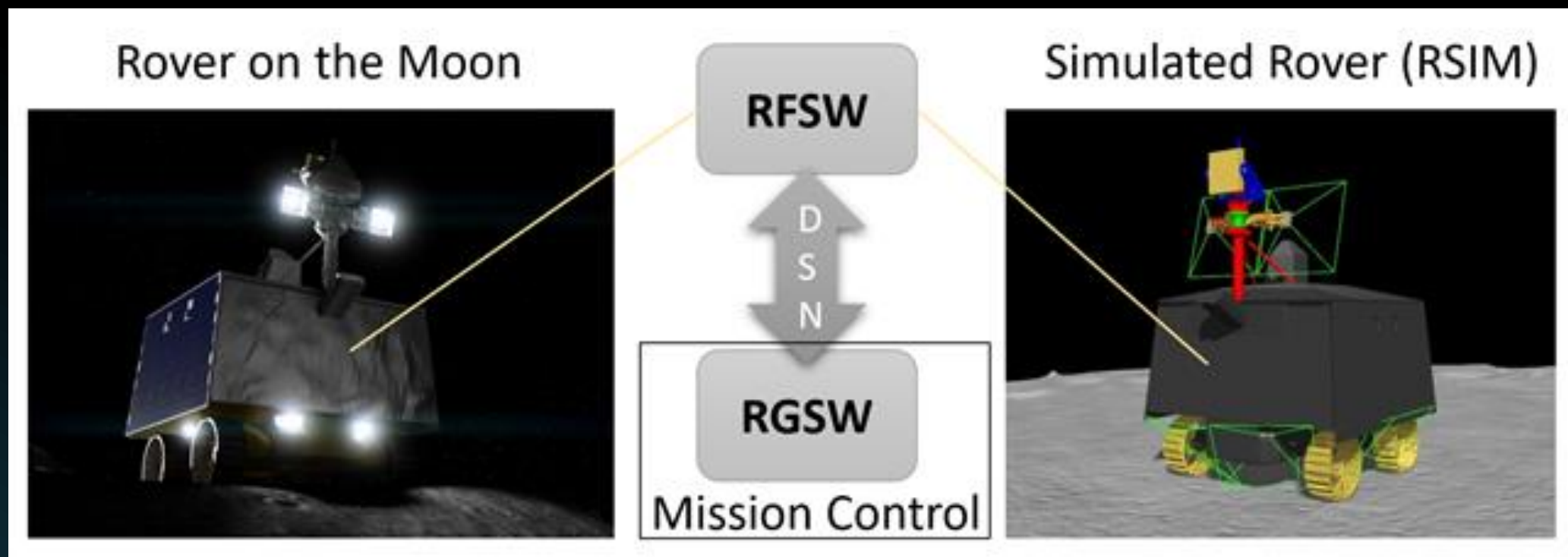
VIPER Rover Simulations (RSIM)

RSIM Architecture

- Gazebo based
- Ensemble of plugins
- Rover model
- Lunar terrain
- Lunar visual environment
- Rover sensors
- Rover actuators
- Fault injection



RSIM/RFSW Integration



- Devices modeled at the protocol level
- Connected via virtual serial ports/UDP (socat)

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VIPER Rover Software Development

Software Test Platforms

Supporting multiple platforms

- Different levels of fidelity
- Ease of access and tool support

Linux laptops and servers

- Familiar development environment for software team
- Immediate availability
- Advanced tools (valgrind, cachgrind...) for debugging and unit-testing

PPC Software Emulation (Qemu RAD750) with VxWorks

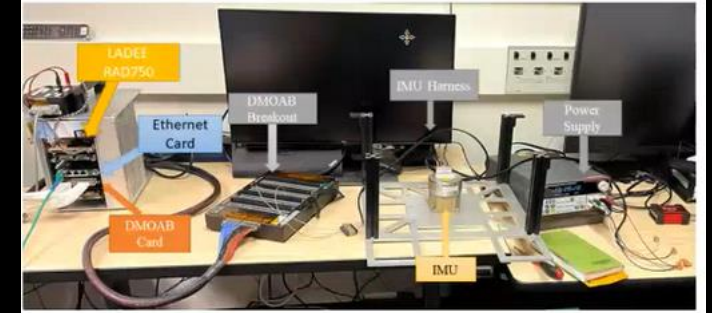
- Flight forward processor (big endian), memory, operating system, compiler toolchain
- Available on every developers laptop

Software Development Units (SDU) from previous mission

- Early availability of similar processor and accessory cards
- Risk mitigation such as early performance measurements etc

Engineering Development Units

- Requirements verification



Agile Development and DevOps

VIPER as a mission follows waterfall model

Rover Software is implemented in 7 build cycles/releases

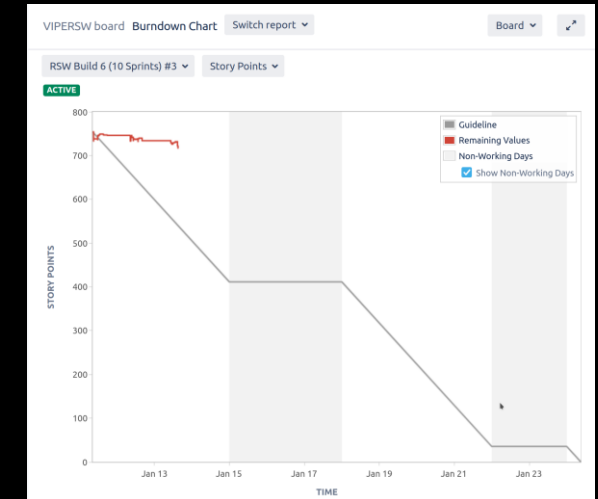
- Build spec defining the feature set
 - Build requirements
 - Software requirements
- Acceptance testing
- Integration and test phase with customers after release

Agile development within the build cycles

- 2 week sprints
- Concluding in project-open ShowAndTell

Development operations

- Continuous integration environment
- Building all sources on both supported platforms
- Running all automated tests: unit tests, subsystem test, end-to-end tests (RSIM)



Bamboo My Bamboo Projects Build Deploy Specs Reports Create

Build dashboard VIPERSW

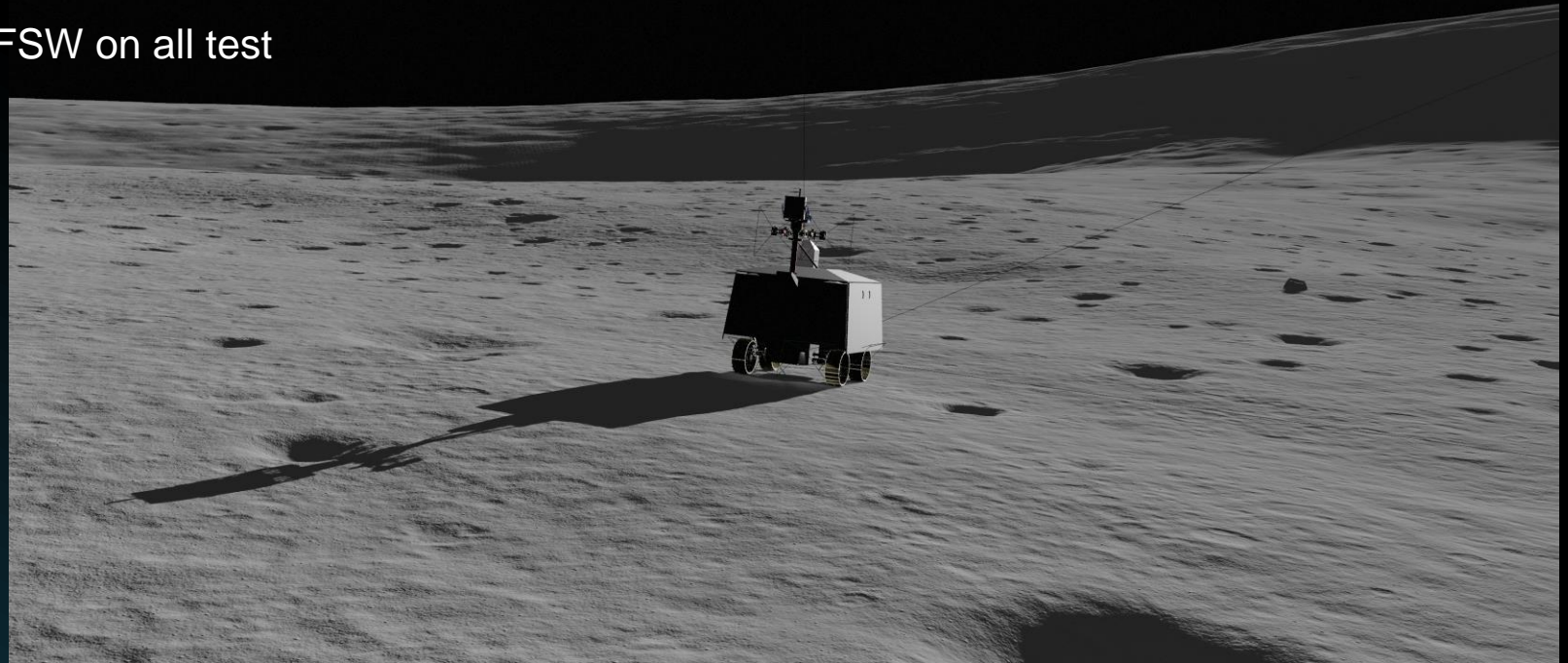
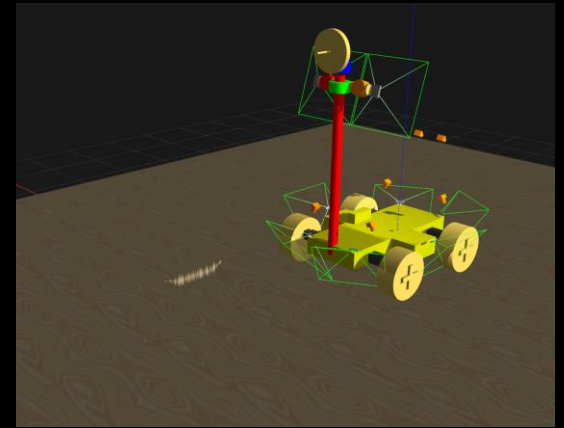
Project wallboard Project settings

Plans Repositories

Plan	Build	Completed	Tests	Reason
EZE test	#1589	12 minutes ago	No tests found	Manual run by Kitchin, Joseph A. (ARC-TI)[KBR Wyle Services, LLC]
QEMU	#49	16 minutes ago	No tests found	Manual run by Utz, Hans (ARC-TI)[KBR Wyle Services, LLC]
RFSW (18.04)	#1289	8 months ago	2884 passed	Changes by Tardy, Antoine (ARC-TI)[KBR Wyle Services, LLC]
RFSW (20.04)	#798	3 hours ago	3759 passed	Manual run by Tardy, Antoine (ARC-TI)[KBR Wyle Services, LLC]
RFSW Nightly	#46	14 hours ago	No tests found	Scheduled
RGSW (18.04)	#1003	5 months ago	No tests found	Manual run by Watkins, Jason (ARC-TI)[KBR Wyle Services, LLC]
RGSW (20.04)	#703	4 hours ago	144 passed	Manual run by Utz, Hans (ARC-TI)[KBR Wyle Services, LLC]
Riptide test	#321	14 hours ago	15 passed	Scheduled
ROS 2	Never Built			
RSim (18.04)	#542	8 months ago	No tests found	Scheduled
RSim (20.04)	#414	54 minutes ago	No tests found	Manual run by Kitchin, Joseph A. (ARC-TI)[KBR Wyle Services, LLC]
VxWorks Kernel	#92	6 hours ago	No tests found	Changes by Spain, Ivan M. (JSC-ER111)[Jacobs Technology, Inc.]

End to End Testing With RSIM

- RSIM as Rover Stand-in
 - Emulating all devices at the protocol level
 - Hi-fidelity simulation of lunar optical environment (cameras, light sources, optical surface properties)
- Running w/ unmodified RFSW on all test environments
- Chain including RSIM, RFSW, RGSW and ground tools such as YAMCS
- Python scripting of test procedures





Status

- Build 6 of 7 started in December
- Feature complete with Build 6
- About 1 year from SW delivery
- Less than 2 years from launch (late 2023)

Questions?

